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CRINANITE-PICRITE INTRUSIONS IN THE NEBO DISTRICT OF NEW SOUTH WALES

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Introduction

Diamond drill holes put down in the Nebo district in the Southern Coalfield of New South Wales, have intersected a series of basic sills and or laccoliths in flat-lying Triassic (Narrabeen) and Permian (Upper Coal Measure) sediments. Petrological studies of the igneous rocks, undertaken as part of the research programme of the Mineragraphic Section of the Commonwealth Scientific and Industrial Research Organization (Mineragraphic Reports Nos. 357, 413, 457) have revealed that some of the sills or laccoliths are composite crinanite-picrite intrusions. The locations of the bores and the surface geology are shown in Fig. 1.

The crinanite-picrite intrusion of Nebo No. 6 Bore

Intrusive basic rocks were cut between the depths of 138 feet (R.L. 1,034 ft. 9 in.) and 399 feet (R.L. 773 ft. 9 in.) in the Nebo No. 6 bore, establishing the presence of an apparently concordant, flat-lying intrusion with a total thickness of about 260 feet, and with its base 36 feet above the uppermost coal seam (No. 1 seam) intersected in the bore. The strata above and below the igneous rock are metamorphosed for a foot or so, and belong to the Narrabeen Series of the Triassic. The bore is adjacent to the basaltic occurrence mapped by Harper (1915) as the Cordeaux Flow, and the possibility arises that the intrusive rock is a continuation underground of this occurrence. Hand specimens were supplied at 10 foot intervals throughout the intrusion, together with specimens of all contacts and lithological changes.

Examination of the material shows that the intrusion consists of typical crinanite in its upper 150 feet, changing abruptly, without any gradation, to picrite at 291 feet below the collar of the drill hole. The picrite layer continues to a depth of about 375 feet, and then grades downward into typical crinanite at 392 feet. This lower crinanite shows a chilled margin against the floor rocks at 398 feet below the surface.

Crinanite

The crinanite (olivine-analcite-titanaugite-dolerite) is a tough dark grey-black, fine-grained rock, speckled with small transparent crystals of felspar. Thin sections (Pl. II, fig. 1) show that it consists essentially of olivine, titanaugite, plagioclase felspar, analcite, a little iron ore, biotite and apatite. Some sections contain chlorophaeite, or serpentine, and some contain calcite.

The olivine occurs in two generations. The earlier-formed olivine occurs as idiomorphic to corroded phenocrysts, up to 2·0 mm. across, with a tendency to associate in clusters. It is a magnesia-rich variety, with 2V about 90°, and is

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optically positive. In many of the sections it is free from any alteration to serpentine, but in others incipient alteration has affected both the phenocrysts and the groundmass crystals, and particularly the latter. These, the second generation olivine, are small crystals 0·1 mm. or less in diameter, restricted to the felspathic "groundmass".

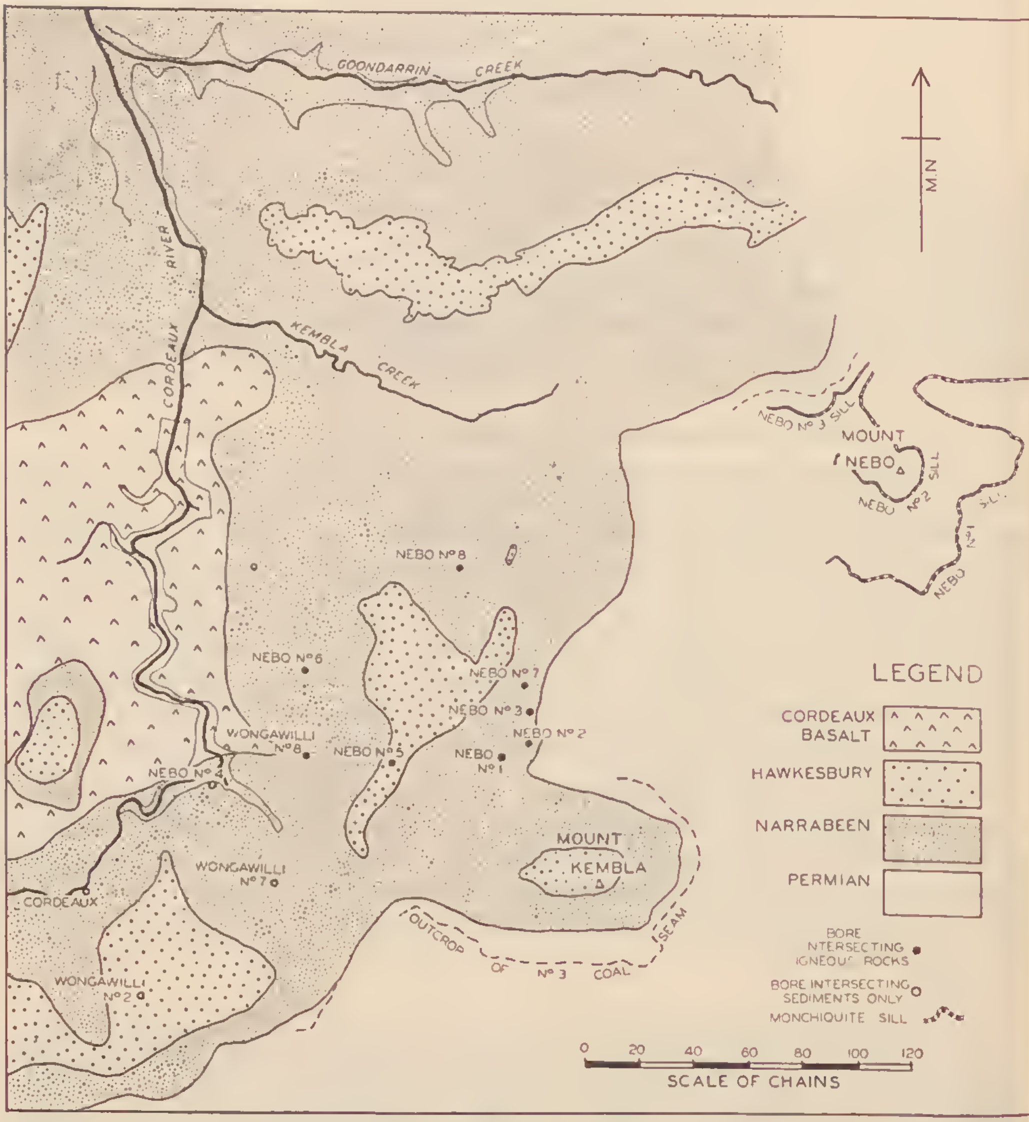


Fig. 1.—Location of the Nebo and Wongawilli Bores. (Geology from Harper, 1915.)

The titanaugite is a deep violet variety, that tends to enclose some of the olivine phenocrysts, but not the small groundmass olivine crystals, and shows prominent ophitic relationship with the plagioclase laths. The individual areas of ophitic titanaugite are about 3·0 to 5·0 mm. across. The titanaugite is pleochroic from deep violet to pale violet or pale yellow, and has 2V about 50°, and is optically positive. A series of micrometric analyses of specimens at vertical intervals through the crinanite (Table 1) show that in most sections the volume of titanaugite equals or exceeds that of olivine. There is some suggestion of downward increase in the total proportion of olivine and titanaugite, but no marked accumulation at any horizon.

The felspar consists of lath-shaped crystals of labradorite (An_{60}), about 0·1 mm. or less in length, with occasional phenocrysts up to 1·25 mm. across. The maximum extinction angle on the laths, in the symmetrical zone, is about 35°, but the larger crystals, which are zoned, have more basic cores and more sodic margins.

The analcite occurs in small cloudy interstitial patches, which are isotropic, and as veinlets and films intersecting and replacing the adjacent plagioclase laths. Occasional small patches of pale greenish chlorophaeite also occur interstitially. Some of these show concentric banding, and some contain numerous spherulitic growths of the same apparent composition. In some sections strongly pleochroic brown biotite occurs as minute flakes dispersed between the felspar laths.

Iron ore occurs as relatively coarse crystals, up to 0·25 mm. across, with a tendency to ophitic intergrowth with the felspar. It also occurs intergrown with the titanaugite, and encloses or is moulded on small crystals of olivine. Small needles of apatite are dispersed through the felspathic areas and in the analcite.

The top of the crinanite is marked by a layer of pale violet coloured porcellanite, showing bedding, which dips at 25° to the axis of the bore, and is charged along the bedding planes and joints with films of pyrite. It was apparently "rafted" from the roof, since above it is a thickness of about 12 inches of deuterically altered crinanite, in which the felspar and titanaugite are largely preserved, but the olivine and interstitial material are completely converted to chlorite. The texture, however, is not that of a chilled phase, but about as coarse as that of the crinanite as a whole.

At the immediate under-contact of the porcellanite layer there is a chilled zone about 2 to 3 mm. thick, containing minute relicts of undissolved porcellanite. One or two narrow beds of the original shale are still outlined in the chilled crinanite by aligned inclusions. A micro-network of felspar penetrates into the adjacent bedding planes of the porcellanite, and in one place was rafting off a small piece of porcellanite when crystallization occurred. This "chilled margin" is clouded with minute inclusions. It gives place downwards to a discontinuous band about 1·0 cm. thick, consisting of a medium-grained felspathic rock, with equigranular texture, and containing a few small prismatic crystals of titanaugite and associated laths of ilmenite, but no olivine. This passes down into a second layer of fine-grained chilled crinanite, about 5·0 mm. thick, and presumably represents a vein that penetrated along a bedding plane of replaced shale. The chilled band contains abundant serpentinized olivine, possibly filtered out of the felspathic layer. Below this second chilled band is a lens-like patch, about 2·0 cm. wide, of coarse-grained ophitically intergrown basic plagioclase and titanaugite, practically free from olivine, in which the individual grains are 2 to 3 mm. across. This patch has a "pegmatitic" appearance and passes downwards into normal crinanite, rather sharply.

The base of the crinanite, in contact with the picrite layer, is a little finer grained than the rock in the interior of the crinanite layer (Table 3), but there is no significant chilled margin. It would appear that during the intrusion of the crinanite, the roof and floor rocks were sufficiently heated to preclude chilling on any large scale, though cooling was sufficiently rapid from the intrusion as a whole to develop a relatively fine-grained texture throughout, and to prevent any significant sinking of the olivine crystals in the mass.

Two chemical analyses of the crinanite in Nebo No. 6 bore were made by the Australian Iron & Steel Co., with the results shown in Table 2. One sample is taken from well up in the crinanite body, and the other from 4 inches above the sharply defined top of the picrite. As will be seen, the two specimens are chemically identical, except that the lower specimen contains 1·6 per cent more magnesia, and 0·7 per cent less alkalis than the higher specimen. This increase in MgO corresponds to the slight downward increase in femics noted for the micrometric analyses. The crinanite is a little more basic than the adjacent Cordeaux basalt (No. 4), containing less silica, alumina, and alkalis, and more magnesia and lime, but closely similar to the Robertson flow (No. 5). Its general resemblance to the type crinanite can be seen by comparison of analyses Nos. 1 and 2 with Analysis A of Table 2.

The Picrite

From a depth of 291 feet downwards there is a layer of ultrabasic rock, here termed picrite, or perhaps better analcite-picrite.

The picrite is coarsest grained in the 30 or so feet immediately beneath the base of the crinanite. It is a dark greenish-black rock, with a granular texture, and a tendency to be friable where the olivine is serpentinized (Pl. II, fig. 2). It consists essentially of plagioclase laths up to 4·0 × 1·0 mm., ophitic plates of titanaugite 5·0 × 5·0 mm., and abundant idiomorphic crystals of olivine up to 4·0 × 1·5 mm. but mostly smaller, together with lesser iron ores, set in a matrix of abundant cryptocrystalline chlorite, analcite, zeolites, abundant apatite in the form of needles, and a little brown biotite and calcite. Commonly the rock has undergone severe deuteric alteration, and the olivine shows considerable alteration to serpentine, but with little or no precipitation of iron oxides, indicating the magnesian character of the olivine. The felspar is frequently replaced by analcite or zeolite or by chlorite. The chief zeolite is an optically positive variety, with a 2V about 45°, which indicates that it is heulandite or thomsonite. It tends to form veinlets in the plagioclase laths, and radiating clusters against the chlorite. The chlorite also, in some instances, shows a tendency to form radiating clusters. The analcite is generally abundant, and tends to form relatively large intersertal areas, as well as impregnate the felspar.

The felspar is predominantly labradorite, about An_{60}, and shows a maximum extinction in the symmetric zone of about 35°. The quantity of felspar decreases somewhat in the first 30 feet below the upper surface of the picrite, and then increases again. The change is accompanied by a progressive decrease in grain size (Table 3), and a decrease in the proportions, and grain size of the olivine crystals and the titanaugite plates, leading to an eventual downward transition to a crinanite (Table 1) in all respects identical to that of the upper part of the intrusion.

The olivine is a magnesia-rich variety. It occurs as idiomorphic crystals, showing little or no corrosion, frequently in polysomatic groups, or is poecilitically enclosed in the titanaugite. It commonly contains unequally distributed minute octahedra which may be magnetite or chromite. At some levels, and particularly near the top of the picrite layer, it tends to be more or less serpentinized, but in others it shows only marginal alteration, or is quite fresh. Where severely serpentinized it has also been in part replaced by both chlorite and calcite, but this is not common. Where alteration has been severe, there is some tendency for the unaltered kernels of olivine in a single original crystal to be forced apart, and "groundmass" material thrust in between.

The pyroxene is a titanaugite, generally deeper coloured towards the margins than in the cores of the crystals. It occurs as large platy, ophitic crystals, enclosing idiomorphic crystals of olivine, some iron ore, and commonly, laths of plagioclase. In addition there are small prisms of titanaugite, of deep colour, in the "groundmass".

The iron ore consists chiefly of octahedra of magnetite up to 0·5 mm. across, but usually smaller, and shows a tendency to be fringed with a corona of biotite. This brown biotite also develops in seams of serpentine replacing the olivine.

The analcite and the zeolites are concentrated in the upper 50 feet of the picrite intrusion, and below this level they rapidly decrease, the zeolites not occurring in the lower part. Chlorite also is most abundant in this upper zone, where it occurs as intersertal patches, and replaces the felspar. In the lower part of the picrite layer it tends to become rather more crystalline, and forms numerous radial aggregates, and columnar growths around the occasional patches of calcite. The apatite occurs as numerous coarse needles abundantly distributed through the analcite, and in the chloritic patches.

The proportion of olivine increases downwards at the expense of the titanaugite and felspar in the upper part of the intrusion, reaching a maximum of about 46 per cent at a depth of about 325 feet, and then slowly declining again to about 40 per cent. Below 375 feet, this decline becomes more pronounced. The pyroxene is most abundant at the top of the picrite layer, where it is equal to the amount of pyroxene in the crinanite layers. It shows a slow downward increase to about 325 feet, which marks the maximum concentration of ferromagnesians, and then a more rapid decline to less than 10 per cent. Below 372 feet, in the transition zone, it increases in amount rapidly, returning to 18 per cent in the basal crinanite layer. The plagioclase and related components decrease with depth to a minimum at about 325 feet, and then increase steadily to a maximum in the basal crinanite layer.

These changes in composition are accompanied by a progressive downward decrease in grain size, from the coarse-grained picrite at the top of the layer, leading to a complete passage to typical crinanite at about 390 feet, as depicted in Figs. 2 to 4 of Plate II.

In Tables 1 and 3 an attempt has been made to quantify these observations. Table 1 shows the relative proportions of olivine and titanaugite, and other constituents, in the rocks at successive levels in the intrusion. Table 3 shows, for the levels selected, (a) the approximate area of the largest grain of plagioclase, titanaugite and olivine observed in the thin sections, (b) the approximate area of the average grains of these minerals present. So few crystals of titanaugite are present in a single section that the range rather than the average size is shown. The areas given are arrived at by multiplying the two widths of the crystals measured at right angles to each other.

The basal crinanite, which resembles the upper crinanite in every respect, shows a chilled and deuterically altered contact with the underlying sediments at a depth of 398 feet. The chilled margin is split into two layers, each about one foot thick, by a narrow band of metamorphosed shale, presumably "rafted" off the floor during the intrusion process.

Three chemical analyses have been made of the picrite, with the results shown in Table 2, Analyses 6, 7, 8. One sample (No. 6) was taken from the top of the picrite body, two inches below its contact with the upper crinanite layer. The second (No. 7) came from the layer showing maximum concentration of the ferromagnesian minerals, at 323 feet, and the third (No. 8) came from a depth

TABLE 1

Micrometric Analyses showing proportions of Olivine and Titanaugite relative to other Constituents in the Crinanite-Picrite Intrusion of Nebo No. 6 Bore.

Rock	Depth ft.	Olivine %	Titanaugite %	Remainder %
Crinanite	141	13·7	16·7	69·6
	175*	13·5	22·6	63·9
	232	17·6	17·1	65·3
	258	18·1	18·2	63·7
	290 8in.*	17·2	22·4	60·4
Picrite	291 2in.*	38·1	17·4	44·5
	313	40·0	13·3	46·7
	323*	46·0	15·2	38·8
	333	44·3	9·9	45·8
	364*	41·2	9·6	49·2
	372	40·1	8·9	51·0
Transitional	382	27·3	15·9	56·8
Crinanite	392*	18·5	18·5	63·0
	397	12·0	12·0	76·0

* chemically analysed rocks of Table 2.

of 364 feet, in the lower part of the picrite proper. Their richness in magnesia and their paucity of lime and alumina emphasize the distinctness of the picrite from the crinanite. Of the three, analysis No. 7 shows the maximum contents of magnesia and total iron, as would be expected. The relatively high Fe_2O_3 content of Nos. 6 and 8, compared to No. 7, is attributable to analytical error in Nos. 6 and 8.

Comparison of these analyses with that of the picrite developed by differentiation in situ from a crinanite magma in the Garbh Eilean sill of the Shiant Isles (Table 2, Analysis B) shows that the analysis of the most olivine-rich horizon of the Nebo picrite, as represented by the rock at 323 feet depth (Analysis No. 7), closely resembles that of the Garbh Eilean picrite.

The basal crinanite, at 392 feet, was analysed also. The analysis (Table 2, Analysis 3) resembles those from the upper crinanite layer. The basal crinanite has a slightly higher silica content and slightly lower magnesia and lime contents than the upper crinanite, and bears a closer resemblance to the analysed Cordeaux basalt (Table 2, Analysis 4) than does the upper crinanite.

The Development of the Intrusion

A number of factors suggest that this crinanite-picrite body resulted from two successive, but closely related intrusions.

The downward passage from picrite to crinanite in the lower 100 feet of the sill is clear evidence that the two rocks are closely related in origin. The picrite would appear at first sight as an ultrabasic differentiate of the crinanite magma, formed in situ by the sinking and accumulation of olivine above the floor of chilled crinanite.

However, various features establish that this composite intrusion is not the product of differentiation in situ, namely:—

(i) the relatively homogeneous nature of the crinanite layer forming the upper half of the laccolith, apart from the purely textural differences in its chilled upper surface.

(ii) the abrupt change from typical unaltered crinanite to the much coarser grained, olivine-rich, and serpentinized picrite. The change is of the nature of a knife-sharp contact, with no trace of gradation.

(iii) the absence of any layer above the picrite which would correspond to the felspar-enriched, olivine-impoverished magma that would be the necessary counterpart of the picrite layer.

It is concluded, therefore, that the picrite is a differentiation product formed *before the intrusion* of the magma, and that the intrusion occurred in two stages. the first of which gave rise to the crinanite layer of the upper half of the laccolith, and a second which introduced the picrite layer.

The absence of a chilled margin of the picrite against the upper crinanite layer, and the fact that it is at this contact that the picrite is coarsest-grained, suggests that the picrite layer was intruded at the base of the upper crinanite layer while the latter was still hot, but after it had solidified, because there was no mingling of magmas at the contact, and the volatile constituents that caused the deuteric alteration of the picrite did not penetrate the adjacent crinanite. There was, therefore, a short time interval between the two stages of intrusion.

The simple picture of two successive intrusions is complicated, however, by the gradual downward transition of the picrite layer in the Nebo No. 6 bore, first to an increasingly basic phase and thence into typical crinanite, with a chilled margin against the underlying sediments.

Two alternative pictures of the second stage of the intrusion can be advanced:—

The less probable is that within the magma chamber where differentiation occurred, an original crinanite magma differentiated with the production of a localized layer of picrite, when the sequence of rocks within the chamber could have been as follows:—

1. crinanite magma (top)
2. a layer of magma enriched in felspathic constituents and impoverished in olivine
3. picrite layer
4. undifferentiated crinanite magma.

The first intrusion drew off the upper layer of crinanite, plus possibly the felspathic differentiate, though this is not found in the bore. The second stage gave rise to an intrusion of picrite, followed up by some of the undifferentiated crinanite from below, thus giving the observed gradation of picrite downwards into crinanite.

The more probable alternative is that the differentiation within the magma chamber of an original basaltic magma gave rise to a body of fluid crinanite in the upper part of the chamber, with a relatively thinner body of picrite formed below it by the sinking of early-formed olivine, and the upward displacement of an equivalent volume of undifferentiated basaltic magma. The first stage of intrusion drew off the bulk, but not all of the crinanite magma.

The second stage of intrusion, following soon after, introduced *more* crinanite at the base of the laccolith. As the overlying rocks (including the upper crinanite), were arched up, or lifted up, increasingly picritic magma following behind the crinanite forced its way in above this newly introduced chilled or rapidly solidified layer of crinanite, so that the order of superposition obtaining

TABLE 2

Chemical Composition of Crinanite and Picrite from Nebo No. 6 Bore.

	1	2	3	4	5	A	6	7	8	B
SiO_2	44·8	44·7	46·35	46·20	44·57	43·94	40·2	40·30	41·1	40·62
Al_2O_3	15·6	15·6	15·91	17·44	15·30	14·03	9·0	6·30	10·9	8·93
Fe_2O_3	5·1	5·0	1·45	1·30	3·20	1·95	5·4	4·12	7·0	0·57
FeO	7·2	6·3	9·95	9·54	7·83	11·65	8·6	10·83	6·4	12·61
MgO	9·2	10·8	9·02	7·38	10·04	10·46	20·2	24·95	21·7	26·31
CaO	10·3	10·7	8·29	9·02	10·00	8·99	6·2	3·99	4·8	5·64
Na_2O	2·7	2·6	3·58	3·69	1·94	2·63	2·4	1·52	2·3	1·32
K_2O	1·9	1·1	1·68	1·10	1·39	0·33	1·0	0·80	0·4	0·13
H_2O+	0·5	0·2	0·11	2·11	3·21	2·31	1·0	4·08	0·8	2·19
H_2O-	0·5	0·8	1·01	0·09	1·09	0·85	3·6	1·44	3·3	0·61
CO_2	n.d.	n.d.	tr.	0·04	0·01	0·16	—	nil	—	0·03
TiO_2	1·5	1·5	1·98	1·30	1·01	2·45	0·9	1·28	0·9	0·82
P_2O_5	0·4	0·4	0·53	0·56	0·41	0·20	0·2	0·07	0·3	0·15
MnO	0·7	0·9	0·20	0·17	0·29	0·32	0·6	0·35	0·7	0·39
Cl	nil	nil	tr.	—	0·01	—	—	0·01	nil	0·01
SO_3	nil	nil	tr.	—	nil	—	nil	0·01	nil	—
BaO	—	—	—	0·03	0·05	—	—	—	—	—
	100·4	100·2	100·06	99·97	100·43*	100·04	99·3	100·06	100·6	100·36†

*NiO 0·05
Cr_2O_3 0·01
V_2O_5 0·02

†NiO 0·03

1. Crinanite at 290 ft. 8 in. (4 inches above picrite) in Nebo No. 6 Bore.
Analyst: Aust. Iron & Steel, Ltd.

2. Crinanite at 175 ft. in Nebo No. 6 Bore.
Analyst: Aust. Iron & Steel, Ltd.

3. Crinanite at 392 ft. (base of sill) in Nebo No. 6 Bore.
Analyst: G. C. Carlos.

4. Cordeaux basalt (analcitic-ophitic titanaugite basalt) ½ mile east Wanyambilli Trig. Station. (*Mem. Geol. Surv. N.S.W.*, No. 7, p. 289.)

5. Robertson basalt (analsitic-olivine-basalt), 5 miles west of Jamberoo. (*Mem. Geol. Surv. N.S.W.*, No. 7, p. 288.)

6. Picrite at a depth of 291 ft. 2 in., Nebo No. 6 Bore.
Analyst: Aust. Iron & Steel, Ltd.

7. Picrite at a depth of 323 ft., Nebo No. 6 Bore.
Analyst: G. C. Carlos.

8. Picrite at a depth of 364 ft., Nebo No. 6 Bore.
Analyst: Aust. Iron & Steel, Ltd.

A. Crinanite, dyke, 1 mile north of Inver Cottage, Jura (Geology of Knapdale, Jura and North Kintyre, *Mem. Geol. Surv Scotland*, 1911, p. 118).

B. Picrite, south face of Garbh Eilean, at shingle beach, Shiant Isles (*Quart. Jour. Geol. Jour.*, 1930, 85: 371).

TABLE 3

Comparative Grain Size of Crinanite and Picrite relative to depth in Nebo No. 6 Bore.
(100 units = 0·4225 sq. mm.)

Rock	Depth ft.	Plagioclase	Titanaugite (ophitic patches)	Olivine
Crinanite	141	28 6 (av.)	1,000 750	280 150 (av.)
	258	90 (rare) 35 6 (av.)	3,200 2,400	800 375 150 (av.)
	290 8in.	20 6 (av.)	2,400 1,400	450 375 150 (av.)
Picrite	291 2in.	900 (freq.) 600 (av.)	6,300 5,850	1,200 1,100 150 (av.)
	291 8in.	400 (freq.) 200 (av.)	4,000 2,625	1,000 750 150 (av.)
	313	200 (occ.) 30	4,500 3,000	1,260 1,200 300 (av.) 35
	323	200 (occ.) 20 (av.) (altered)	4,400 4,200 3,600	1,500 650 750 300 (av.) 50
	333	20 5 (av.)	2,500 2,400	450 385 350 300 (av.)
	344	500 (rare) 20 6 (av.)	2,400 1,500	600 500 200 } 150 } (av.)
	354	240 (occ.) 50 40 10 (av.)	2,925 2,700 1,750	600 160 (av.)
	364	20 6 (av.)	1,500 1,200 1,000	900 680 150 (av.)
	372	45 6 (av.)	1,500 900	500 88 (av.)
Crinanite	392	18 6 (av.)	600 400	530 270 150 (av.) 56

within the magma chamber was *reversed* within the laccolith, much as the order of superposition obtaining in a magma chamber is reversed when differentiated layers of magma are *extruded*. In this way the most basic picrite intruded was brought uppermost, into contact with the previously intruded, and still hot, upper crinanite layer. Sufficient fluidity remained after intrusion to permit some gravitational differentiation in situ, as a result of which olivine in the olivine-rich picrite layer now at the top of the column began to *sink back towards the crinanite below it*. This resulted in some concentration of olivine a little distance below the upper picrite contact, where the felspar, at least, occurs as distinctly smaller crystals than the felspar close to the upper contact, and would explain the peculiar downward decrease in amount of pyroxene in the picrite. This picture of the second stage of intrusion removes the necessity to postulate a felspathic, olivine-poor counterpart of the picrite—a rock not encountered in either the Nebo No. 6 or the Nebo No. 7 bores.

The crinanite-picrite intrusion of Nebo No. 7 Bore

The Nebo No. 7 bore which is a mile south-east of the No. 6 bore (Fig. 1), intersected a composite intrusion 40 feet thick at a depth of about 317 feet (R.L. 719 ft.), and 3 feet above the No. 2 coal seam, on a horizon about 50 feet stratigraphically lower than the intrusion cut in the No. 6 bore. The Nebo No. 7 intrusion consists of an upper layer, 12 feet thick, of crinanite, and a lower layer, 27 feet 6 inches thick, of picrite. The contact between the two layers is at 329 feet 6 inches depth and is a knife-sharp contact, as in the Nebo No. 6 intrusion. Samples of the two layers from immediately above and below this contact were examined. The rocks appear identical with those in the Nebo No. 6 intrusion,

TABLE 4

Micrometric Analyses of Crinanite and Picrite in Nebo No. 7 Bore.

	Olivine	Titanaugite	Remainder
Crinanite	16·4	16·4	67·2
Picrite	39·2	10·6	50·2

TABLE 5

Chemical Composition of the Crinanite and Picrite in the Nebo No. 7 Bore.

	Crinanite	Picrite
SiO_2	46·16	39·86
Al_2O_3	15·44	8·73
Fe_2O_3	3·08	3·39
FeO	8·72	9·62
MgO	9·57	23·00
CaO	8·93	4·40
Na_2O	2·38	1·88
K_2O	1·46	0·49
H_2O+	0·05	2·73
H_2O-	1·09	4·26
CO_2	nil	nil
TiO_2	2·51	1·22
P_2O_5	0·51	0·06
MnO	0·32	0·22
Cl	0·10	0·10
SO_3	0·10	0·10
	100·06	100·06

Analyst: G. C. Carlos.

and no detailed petrographic description is called for. Micrometric analyses showing the proportions of olivine and titanaugite were made for comparison (Table 4).

Chemical analyses of these two rocks, from immediately above and below the contact at 392 feet 6 inches are given in Table 5. The crinanite layer is generally similar in composition to that of the crinanite in the Nebo No. 6 bore, and particularly similar to the basal crinanite layer. The composition of the picrite is intermediate between those of the analysed specimens of picrite at 323 feet and 364 feet in the Nebo No. 6 bore.

The composite intrusion in the Nebo No. 7 bore may represent the thinned edge of the intrusion cut in the Nebo No. 6 bore, but it is more likely that it is an independent composite intrusion, because it occurs at a lower stratigraphic than the Nebo No. 6 intrusion. Moreover, if it is part of the Nebo No. 6 intrusion, the intrusive body must have a very narrow elongated form, in view of the different nature of the intrusions cut by the Wongawilli No. 8 bore, which lies closer to the Nebo No. 6 bore, and in the Nebo Nos. 1, 2 and 3 bores, which are adjacent to the Nebo No. 7 bore (Fig. 1).

The intrusions in the Wongawilli No. 8 Bore

The Wongawilli No. 8 bore intersected two separate intrusions separated by 65 feet of Narrabeen sediments. The upper intrusion, which was met at 70 feet. (R.L. 1,107 feet), was 100 feet thick, and in the hand specimen appeared identical with the crinanite layers of the Nebo No. 6 and Nebo No. 7 bores. This is confirmed by thin sections. The lower intrusion, which is 65 feet thick, was met at a depth of 235 feet (R.L. 942 feet), and in the hand specimen closely resembles the picrites of the Nebo No. 6 and Nebo No. 7 bores, but thin sections reveal that it is not a picrite, and actually contains less olivine and pyroxene than the overlying crinanite (Table 6). The lower intrusion is 88 feet 6 inches above the floor of the No. 1 seam, and 199 feet above the base of the No. 3 seam. The upper intrusion is on a horizon 152 feet above the floor of the No. 1 seam.

TABLE 6

Micrometric Analyses of the Upper and Lower Intrusions in the Wongawilli No. 8 Bore.

	Olivine	Titanaugite	Remainder
Upper intrusion (crinanite)	18·9	20·9	60·2
Lower intrusion (close to top)	14·7	13·1	72·2
(deeper)	15·3	12·0	72·7

The resemblance of the lower intrusion to the picrite, in hand specimen, arises from its relatively coarse texture, and the altered condition of its olivine. It contains an abundance of analcite, patches of fibrous zeolite, an abundance of pale green micro- to crypto-crystalline chlorite, and some calcite. The olivine is almost completely altered to serpentine, and the felspars are, to a considerable degree, replaced by analcite and chlorite. It is best described as an analcite-olivine-titanaugite dolerite, and is closely akin to a crinanite.

A chemical analysis (Table 7, No. 1) shows it to contain more alumina and soda, and less magnesia and lime, than the crinanites proper (Table 2), as would be expected from the micrometric analyses (Table 6). It seems likely that this rock represents a somewhat olivine-impoverished differentiate of the magma that gave rise to the picrite, and that the two are related in origin.

The intrusion in the Nebo No. 8 Bore

In the Nebo No. 8 bore a basic sill 23 feet thick was encountered at a depth of 403 feet (R.L. 693) in the centre of the No. 2 coal seam, which is cindered. It is 28 feet below the floor of the No. 1 seam, and 74 feet 6 inches above the base of the No. 3 seam. The top and bottom contacts are each about 18 inches thick and consist of a chilled, bleached, basaltic rock. The core of the sill is medium to coarse-grained, and in hand specimen resembles the picrite from the Nebo Nos. 6 and 7 bores, and the lower intrusion from the Wongawilli No. 8 bore. A series of thin sections over 2-foot intervals, reveals that the intrusion is an analcite-olivine-dolerate of uniform composition. It consists of idiomorphic phenocrysts of olivine, up to 1·0 mm. long, but generally smaller, set in a groundmass of ophitically intergrown titanaugite and labradorite, iron ore, chlorite and analcite. The olivine crystals tend to occur in clusters, and to be enclosed in the titanaugite,

TABLE 7

Chemical Compositions of Intrusions in the Wongawilli No. 8 and the Nebo No. 8 Bores.

	1.	2.
SiO_2	44.40	42·45
Al_2O_3	16·49	14·40
Fe_2O_3	3·67	4·46
FeO	6.28	6·54
MgO	7·97	9·34
CaO	7·98	7·00
Na_2O	3.61	3·41
K_2O	1·38	1·12
H_2O+	4·48	6·84
H_2O-	1.87	2·57
CO_2	nil	nil
TiO_2	1·83	1·78
P_2O_5	0·34	0·22
MnO	0.25	0·28
Cl	0·01	0·01
SO_3	0·01	0·01
	100·57	100·43

1. Wongawilli No. 8 Bore, lower part of lower intrusion.
2. Nebo No. 8 Bore, at 418 feet.

Analyst: G. C. Carlos.

and are almost completely altered to serpentine. The titanaugite forms ophitic areas up to 2·5 mm. across, and is generally fresh and deep purple, but in the bleached rocks at the contacts is altered to chlorite, iron ore and (?) sphene. The labradorite occurs as laths and plates about 1·0 mm. long or smaller, and the iron ore forms octahedra up to 0·5 mm. across, and is mostly magnetite.

Analcite is abundant, filling interstitial areas up to 1·0 mm. across, and replacing felspar. Some zeolitic material has been introduced, and some areas adjacent to the serpentinized olivines consist of pale green micro- to crypto-crystalline chloritic material. A little calcite is present in the bleached specimens. The alteration of the olivine and the felspar are late-stage changes accompanying the solidification of the rock. No accumulation of olivine by sinking has occurred, despite the relatively coarse texture of the interior of the sill, presumably because the olivine is so inter-grown with the ophitic titanaugite.

The rock closely resembles the lower of the two intrusions in the Wongawilli No. 8 bore, both as regards composition, grain size, and serpentinization of the olivine. Micrometric analyses reveal similar proportions of olivine and titanaugite in the two intrusions (Table 8), and a chemical analysis (Table 7, Analysis No. 2) confirms their general similarity, but shows the Nebo No. 8 rock as containing a little more magnesia, and less lime than the Wongawilli No. 8 rock, which accords with the micrometric analysis.

TABLE 8

Micrometric Analyses of the Nebo No. 8 Bore Intrusion, and the Lower Intrusion of the Wongawilli No. 8 Bore

	Olivine	Titanaugite	Remainder
Nebo No. 8 (418 feet)	15·8	12·6	71·6
Wongawilli No. 8 (lower intrusion)	15·3	12·0	72·7

Analcite-olivine-dolerite in Nebo No. 3 Bore

The Nebo No. 3 bore intersected an intrusion of analcite-olivine-dolerite, 12 feet thick, at a depth of 216 feet 6 inches, one foot below the floor of the No. 2 Coal Seam, which is cindered, and 72 feet above the floor of the No. 3 Seam. This dolerite closely resembles that cut in the Nebo No. 8 bore, at about the same horizon, but could scarcely be continuous with it, in view of the different composition of the intrusions in the more nearly adjacent Nebo Nos. 1, 2 and 7 bores (Fig. 1).

A specimen from 226 feet is a coarse-grained analcite-olivine-dolerate, consisting of idiomorphic crystals of altered olivine and fresh titanaugite in a coarse intergranular groundmass of plagioclase laths, abundant intersertal analcite, small grains of magnetite, and shreds of basaltic hornblende and aegirine-augite. The olivine is completely altered to serpentine (antigorite) and granules of magnetite that have aggregated in the grain boundaries of the olivine.

The titanaugite shows slight marginal alteration to green aegirine-augite where it is in contact with areas of analcite, and occasional small grains of aegirine-augite occur within the analcite areas. Small blades of strongly pleochroic basaltic hornblende are associated with the primary magnetite grains, and with the altered olivine in the vicinity of the analcite areas. The felspar is labradorite, with an extinction angle of about 25° or greater (in the symmetrical zone). In places it is slightly replaced by carbonate and micaceous substances, or invaded by chlorite or serpentinous material derived from the altered olivine crystals, but the bulk of it is fresh.

Crinanite in the Nebo No. 5 Bore

The Nebo No. 5 Bore cut a 9 foot thickness of basaltic rock, with an upper and lower chilled contact, between 614 and 623 feet (R.L. 792 and 783 feet). Its base is 3 feet above the top of the No. 1 Seam, and 12 feet above the floor of this coal seam.

The rock is an analcite-olivine-titanaugite-basalt, with corroded phenocrysts of fresh olivine up to 5·0 mm. long, set in a groundmass of titanaugite in plates up to 1·0 mm. across, ophitically intergrown with analcitized plagioclase laths and small, more or less idiomorphic crystals of olivine about 0·1 mm. across, and rather coarser magnetite. It bears a close resemblance to the crinanite layer of the Nebo No. 6 bore intrusion.

The Cordeaux Flow

To the west of the area drilled, there is an extensive outcrop of basaltic rock (Fig. 1) described by Harper (1915) as the Cordeaux Flow. This basalt occurs on much the same stratigraphic horizon as the sills encountered in the Nebo No. 6 and Wongawilli No. 8 bores.

TABLE 9

Micrometric Analyses showing the amounts of olivine and pyroxene in the Cordeaux basalt

	Olivine %	Titanaugite %	Remainder %
Cordeaux Basalt			
Specimen No. 1	19·6	15·0	64·4
Specimen No. 2	17·6	19·4	63·0
Specimen No. 3	18·7	19·4	61·9
Wongawilli No. 8 Bore			
Crinanite	18·9	20·9	60·2

Three samples from the flow were examined. Their localities are:—

(1) lowest outcrop point below the No. 2 Cordeaux Dam
(2) outcrop below the bridge below No. 1 Cordeaux Dam
(3) specimen containing a vein from below the bridge below Ponton's house.

Thin sections of these specimens reveal that it is an analcite-titanaugite-dolerite, or crinanite, a little coarser-grained than the crinanites in the intrusions, but not otherwise distinguishable from them. The analysis of the rock given by Harper (Table 2, Analysis No. 4) shows that it is slightly more felspathic than the crinanite in the Nebo No. 6 bore, and the type crinanite of Jura; but not greatly different in other respects. Micrometric analyses (Table 9) show that the proportions of olivine and augite are generally similar.

The "vein" in Specimen No. 3 is of the nature of a seam of "crinanite-pegmatite", without sharp walls. It consists of prisms of titanaugite 10 × 3 × 4 mm., plates of labradorite 3 × 3 × 1 mm., iron ores about 1 × 1 mm., and occasional crystals of olivine, about 2 × 2 mm. in a fine-grained groundmass composed of rod-like skeletal crystals of olivine, often in parallel clusters, radial growths of felspar microlites, a little prismatic titanaugite, minute blades of brown biotite, seams and patches of radial zeolite, probably natrolite, and abundant analcite. In occurrence and general character, it resembles the seams of "pegmatitic dolerite" found in the Jurassic dolerite intrusions of Tasmania. Such "pegmatite" would not be expected to develop in a basalt flow; and if at all common, would support the possibility that the Cordeaux "flow" is an exposed sill.

Monchiquites of the Nebo No. I Bore and the Nebo Sills

The Nebo No. 1 Bore intersected a 5 foot thick sill at 184 feet (R.L. 745 feet) immediately below the No. 1 Coal Seam, which is coked at the base, and a 27 foot thick sill at 207 feet (R.L. 702 feet), forming the roof of the No. 2 Coal Seam, which is cindered. The lower sill is 80 feet above the base of the No. 3 Coal Seam, and the upper sill is in a horizon 18 feet higher still.

Specimens from 209 feet and 226 feet reveal that the lower sill is a fine-grained monchiquite, consisting of minute prisms of titanaugite and granules of magnetite, which form a dense felted intergrowth, with only traces of felspar. Occasional microphenocrysts of titaniferous augite occur throughout this groundmass, and where a band of carbonate and analcite, about 1 mm. wide, crosses the rock, the place of the pyroxene prisms is largely taken up by lath-like prisms of basaltic hornblende.

The upper sill is an altered monchiquite consisting of chloritic pseudomorphs after occasional microphenocrysts of pyroxene, sparsely distributed through a dense groundmass which shows something of the texture of the groundmass in the lower monchiquite.

The nearby Nebo No. 2 bore cut a basic intrusion 16 feet thick, lying directly on the No. 2 Coal Seam, at a depth of 138 feet (R.L. 747 feet). The top of this intrusion is 31 feet below the floor of the No. 1 Coal Seam, and its floor is about 80 feet above the base of the No. 3 Seam. In the absence of specimens it is uncertain whether this intrusion is a continuation of the lower monchiquite sill of the No. 1 bore, or of the dolerite occurring beneath the No. 2 Coal Seam in the No. 3 bore.

Harper and Card (1915, pp. 343-345) describe three thin sills of monchiquite (fourchite) in the Permian sediments of Mount Nebo proper. The lowest of the three, which occurs at R.L. 360 feet, has a thickness of 30 feet in its central part, and thins rapidly away from this point. It can be traced at the surface for three and a quarter miles around the mountain. It is mostly fine-grained, with local coarse-grained patches which contain hornblende crystals up to an inch long. It consists essentially of hornblende and titanaugite in a dusky, more or less isotropic groundmass.

A second sill occurs 300 feet higher up, in contact with the No. 5 Coal Seam, and is completely altered and bleached. In places, however, it is separated from the coal seam by as much as 10 feet of sediments, when it is unaltered. The unaltered rock closely resembles the lowermost sill in composition. It is 3 to 4 feet thick and can be traced at the surface for somewhat over a mile.

The third sill is 50 feet higher, and just below the No. 4 Coal Seam. It outcrops for three-quarters of a mile, with a thickness of 30 feet, and is abruptly terminated at either end.

Analyses of the middle and top sills from Mount Nebo are quoted in Table 10. A point of interest is the low magnesia content of both analyses, which corresponds with the absence of olivine from these rocks. The low silica content, in conjunction with high lime and high alkalies, suggests that these rocks are related more directly to the picrites than to the crinanites or dolerites. They could be pictured as developing from the picrites by the complete sinking of olivine and labradorite from that rock, leaving a concentration of pyroxene constituents and alkalies. Something comparable with such a process is indicated by some of the monchiquite dykes at Bendigo and Castlemaine in Victoria, where thin fine-grained monchiquite dykes are found carrying numerous clots of olivine, or olivine and labradorite up to six or eight inches across.

TABLE 10

Chemical Analyses of Monchiquites from Mount Nebo and the John Darling Teschenite Dyke

	1	2	3	A	B
SiO_2	41·72	40·62	41·88	41·42	41·10
Al_2O_3	16·87	13·62	14·14	15·07	14·82
Fe_2O_3	5·90	7·05	5·78	7·93	2·35
FeO	3·87	6·07	6·56	—	10·38
MgO	4·23	5·71	6·61	4·82	9·43
CaO	10·32	10·05	10·07	10·16	10·56
Na_2O	4·99	2·23	4·36	4·00	3·94
K_2O	2·73	2·48	2·28	1·98	1·28
H_2O+	3·67	4·58	3·59	2·73	2·31
H_2O-	0·45	4·58	0·93	0·27	0·39
CO_2	2·54	0·71	0·35	—	0·26
TiO_2	1·70	2·30	3·05	3·14	3·20
P_2O_5	0·85	1·16	0·30	1·57	0·19
MnO	0·15	0·08	0·18	0·20	0·14
BaO	0·13	1·46	n.d.	n.d.	0·06
SrO	0·03	tr.	n.d.	nil	tr.
Cl	0·03	nil	0·01	0·05	tr.
SO_3	nil	0·38	nil	0·37	0·09
S	nil	0·11	n.d.	0·10	nil
V_2O_5	0·02	0·06	n.d.	nil	tr.
ZrO_2	nil	nil	n.d.	n.d.	n.d.
NiO	0·04	nil	n.d.	n.d.	tr.
Li_2O	nil	tr.	n.d.	nil	tr.
	100·24	99·98	100·09	100·21	100·50

1. Monchiquite, middle sill, Mount Nebo (J. C. H. Mingaye, *Mem. Geol. Surv. N.S.W.*, No. 7).
2. Monchiquite, top sill, Mount Nebo (W. H. Stone, *Mem. Geol. Surv. N.S.W.*, No. 7).
3. Teschenite dyke (Big Dyke) at 4 West Junction, John Darling Colliery. *Analyst*: G. C. Carlos.

A. Teschenite, from Paskau, 25 km. W. of Teschen, Mähren, Silesia (A. Johannsen, *A Descriptive Petrography of the Igneous Rocks*, Vol. 4, p. 229).

B. Analcite basalt dyke, ¼ mile WNW. Fernhill Station (G. W. Card, J. C. H. Mingaye and H. P. White, *Rec. Geol. Surv. N.S.W.*, 7 (1902): 97).

The tendency for these monchiquites to develop basaltic hornblende, especially in local coarse-grained areas, or in the presence of calcite and analcite, suggests a genetic relationship between the monchiquites and hornblende rich rocks like the teschenite forming the 60 ft. wide Big Dyke in the main heading of the John Darling Colliery in the Newcastle coalfield, in close proximity to a smaller 9 ft. thick monchiquite dyke.

This teschenite dyke has chilled margins from two to three feet wide on either wall against the coal seam (Borehole seam), and is strongly bleached and altered at the contact, while the coal is coked for about 10 feet from the contact, and over the next ten feet shows crumpling and is partly carbonized.

The core of the dyke is a medium-grained rock consisting essentially of basaltic hornblende, titanaugite, labradorite, analcite, magnetite and apatite, in the proportions shown in Table 11.

TABLE 11

Micrometric Analysis of Teschenite forming the Big Dyke, John Darling Colliery

Hornblende	18·3
Titanaugite	20·0
Magnetite	5.0
Labradorite (analcitized)	44.5
Analcite (clear)	11·0
Apatite	1·2

The basaltic hornblende occurs as idiomorphic prisms, up to 1·5 × 0·75 mm., but generally a little smaller. It shows practically straight extinction, and occurs as free crystals, or as crystals moulded on the titanaugite crystals. It tends to be slightly replaced by chlorite, and in places by zeolitic material, along its cleavages.

The titanaugite is a brownish-violet variety, occurring as idiomorphic stumpy prismatic crystals, about 0·5 × 0·75 mm., with some tendency to occur in clusters. It encloses occasional serpentinized grains of olivine, and crystals of magnetite. The magnetite occurs as octahedra and skeletal crystals up to 1·0 × 1·0 mm. Blades of ilmenite are intergrown with it in a lattice pattern. These crystals are enclosed in or between coarse plates of cloudy, analcitized labradorite, up to 4·0 × 1·0 × 1·0 mm., and pools of clear analcite. Felspar, hornblende and analcite are all studded with needles of apatite, about 0·2 mm. long and 0·01 mm. across. No apatite occurs in the titanaugite.

In addition the rock contains a little calcite, typically associated with the analcite pools, and occasionally with the chlorite in the hornblende, and a little colourless zeolite, with a biaxial negative figure, and 2V about 60°, so that it is presumably natrolite. A chemical analysis of the teschenite is given in Table 10, where it may be compared with that of a teschenite from Paskau, 25 km. west of Teschen, Mähren, Silesia, one of the original teschenites. The John Darling rock contains rather more magnesia, but even so, the rocks are closely similar. The general resemblance of the John Darling teschenite to the Mt. Nebo monchiquites is equally apparent. In addition it shows considerable resemblance in chemical composition to a dyke of analcite basalt (Table 10, B), near Fernhill Station, described by Card, Mingaye and White (1902), despite a complete absence of hornblende from the analcite basalt.

The close association in space and time of the various basalts, picrites, monchiquites, and teschenite, indicates that they were derived from a common source magma.

The numerous xenoliths and xenocrysts of basaltic hornblende in such rocks as the analcite-basalt sill of the Bulli Colliery (Harper and Card, 1915) are evidence that differentiation tended towards the development of rocks like the John Darling teschenite at a number of points within the region, presumably within small cupola-like projections above the main magma chamber. These hornblende crystals subsequently sank into, or were otherwise caught up in, less differentiated magma in which they were no longer in equilibrium.

The adjacent monchiquite dyke, which is 9 feet wide, has a parallel strike to the teschenite dyke, and consists of idiomorphic phenocrysts of olivine, up to 3 mm. long, but mostly 1 to 1·5 mm. long, and occasional phenocrysts of pale violet augite, about 0·75 mm. across, set in a groundmass of abundant prismatic crystals of pale violet titanaugite, and associated brown hornblende, in places moulded on or enclosing the titanaugite prisms, together with a very small amount of plagioclase, in interstitial positions, and some analcite, numerous fine needles of apatite, and small octahedra of magnetite. The olivine is largely altered to serpentine, with residual kernels of olivine, and in places has been largely replaced by calcite, which has invaded the rock generally.

Composite Intrusions in the Mount Murray No. I Bore

The Mount Murray No. 1 Bore, in M.L. 11, Parish of Wongawilli, Camden Co., which is about 9 miles S.W. of Nebo No. 1 Bore, has revealed the presence of related intrusions in this part of the Southern Coalfield. The bore, which penetrated to a depth of 1,247 feet below its collar, at R.L. 1,760 feet, intersected eight separate basaltic intrusions between the depths of 336 feet 6 inches and 1,003 feet (Table 12). The upper five intrusions, which include one which is 80 feet thick, and one 54 feet thick, are intercalated with sediments of the Narrabeen Series (Triassic). The lower three, of which the lowest is 16 feet thick, lie in the Permian Coal Measures. The lowest sill has cindered the Wongawilli or No. 3 coal seam.

The upper group of intrusions consists of titanaugite basalts and dolerites, all distinctly poor in olivine, in contrast to the lowest intrusion, which is olivine-rich.

The 80-foot Composite Intrusion

The 80-foot thick intrusion, extending from 381 feet to 466 feet, is composite. From its chilled top at 381 feet to 387 feet it consists of a coarse-grained titanaugite dolerite, with a few small crystals of chloritized olivine. A specimen from 388 feet consists of an inclusion or zenolith of this coarse-grained dolerite in a dense, fine-grained (chilled) titanaugite-analcite basalt, also poor in olivine. It is possible that the relationship is reversed, and that the specimen represents a xenolith of the basalt caught up in the dolerite.

Specimens of this basalt from 400 feet and 410 feet are somewhat coarser grained than the chilled rock at 388 feet, but are finer grained than, and texturally distinct from, the dolerite above.

A specimen from 411 feet 6 inches is an extremely coarse-grained titanaugite dolerite, in which the titanaugite prisms and plagioclase laths are 2 to 3 mm. long, and up to 0·5 mm. across. This is possibly a pegmatitic phase of the basalt, or part of the dolerite which the basalt has intruded. The next deeper specimens available, from 434 feet and 444 feet, are identical with the medium-grained titanaugite basalt at 410 feet depth.

The next deeper specimens, from 448 feet 6 inches and 453 feet, are both coarse-grained titanaugite dolerites, practically identical with the dolerite at 387 feet. At 461 feet this rock gives place to the chilled top of a relatively fine-grained titanaugite basalt, represented by specimens from 461 feet 6 inches (the chilled top) and 465 feet 6 inches. This lowest intrusion is generally similar to the titanaugite basalt occurring between 388 feet and 448 feet.

Chemical analyses of the coarse titanaugite dolerite from 387 feet, and the underlying titanaugite basalt from 410 feet, are shown in Table 14, Nos. 1 and 2. Both have notably high CaO contents, and relatively low MgO contents, reflecting their relative paucity in olivine, but the basalt from 410 feet is distinctly poorer in MgO than the dolerite. They tend also to be low in total iron content. The richness in TiO_2 relates to their abundant content of titanaugite.

The high CaO and low MgO, in some respects, parallels the composition of the Nebo monchiquites (Table 10).

The 54-foot Composite Intrusion

After passing through only 5 feet of fine-grained sandstone and shale, the bore entered a second composite intrusion, at 471 feet. From 471 feet to about 500 feet it passed through an intrusion of titanaugite dolerite, which shows a fine-grained chilled top at 471 feet, grading downwards into relatively coarse-grained rock (480 feet), that passes back to a chilled lower margin between 490 feet and 500 feet. The coarse-grained rock in the central part of the intrusion consists of abundant idiomorphic crystals of titanaugite, from 0·5 to 1·0 mm. across, partly altered plagioclase laths of similar dimensions, a number of smaller chlorite pseudomorphs after olivine, and coarse crystals of magnetite with intergrown ilmenite, set in a base of chlorite, clear analcite, irregular patches of calcite, and occasional coarse crystals of analcite. At 500 feet there is a thin band of sandstone, and below this is a 25-foot thick sill of titanaugite basalt, relatively poor in olivine, with chilled margins above and below a more coarsely crystalline central portion.

The 16-foot Picritic Sill

The only other intrusion of any thickness is the lowermost, extending from 987 feet to 1,003 feet, at the horizon of the Wongawilli or No. 3 coal seam, which is represented by bands of cindered coal above the intrusion. This is an olivine-rich rock, which, as may be seen from the micrometric analyses of Table 13, closely resembles the rock from 382 feet in the Nebo No. 6 Bore, intermediate between the picrite and the lower crinanite layers of that bore. It has a comparable coarse texture. Deuteric alteration has serpentinized much of the olivine, and analcite has replaced much of the plagioclase. Magnetite-ilmenite crystals, which are relatively coarse-grained, constitute about 3 per cent of the rock, and coarse needles of apatite are numerous.

A chemical analysis of a sample from 996 feet is shown in Table 14, No. 3. Comparison of this analysis with the analyses of the No. 6 picrite, shows, as anticipated, that it is intermediate in composition between the picrite and the basal crinanite, though tending strongly towards picrite.

The analysis contrasts strikingly with those of the MgO-poor rocks in the 381-466 foot intrusion.

The Thin Intrusions

As indicated in Table 12, the other five intrusions are 1 foot 7 inches, 6 feet 5 inches, 6 inches, 12 inches and 12 inches thick, respectively. They may represent very thin intrusions branching off from the same conduits as some of the thicker intrusions, or they may represent the thin extremities of interfingered intrusions which are thicker elsewhere.

TABLE 12

Intrusions in the Mount Murray No. 1 Bore

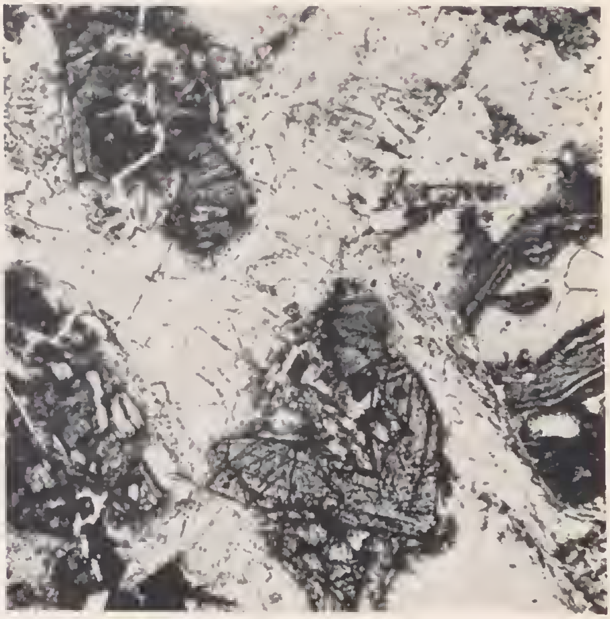
	Thickness		Depth		R.L. of Base	
	ft.	in.	ft.	in.	ft.	in.
Fine-grained titanaugite basalt with very little olivine	1	7	336 5 to 338 0		1,422	0
Titanaugite olivine basalt, much altered and calcitized	6	5	339 4 to 345 9		1,414	2
Composite intrusion of (i) titanaugite dolerite (ii) analcite titanaugite olivine basalt	80	1	385 11 to 466 0		1,294	0
Composite intrusion of (i) titanaugite dolerite, separated by a band of sandstone at 500 feet, from (ii) a fine-grained titanaugite basalt	54	6	471 1 to 525 7		1,234	5
Glassy basalt	0	6	609 6 to 610 0		1,150	0
Bleached glassy basalt	1	0	887 7 to 888 7		871	5
Glassy basalt	1	0	969 7 to 970 7		789	5
Olivine-rich analcite olivine dolerite, or kylite, similar to the picrite-crinanite transition rock in Nebo. No. 6 Bore, at 382 feet.	16	1	986 9 to 1,002 10		757	2

Differentiation

As in the Nebo area, the magma giving rise to these intrusions had undergone differentiation before intrusion occurred. The impression is gained that the various rocks between 381 feet and 525 feet constitute a composite or multiple intrusion of rock types of generally similar chemical composition, all with an abundance of titanaugite and a paucity of olivine. In view of the related, but olivine-rich, character of the lowest sill, it seems likely that the magma differentiated into an olivine-poor upper layer, and an olivine-rich layer prior to intrusion, and was then injected in a series of pulsations, sufficiently spaced in time to permit the chilling of the previously intruded magma.

The intrusions all appear to have the form of sills, and can be expected to be of variable lateral extent, with a possible interfingering of intrusions that rose up separate, but not unduly widely spaced, conduits, a repetition of the conditions in the Nebo area.

1



2

3

4

FIG. 1.—Upper crinanite, from 290 ft. 8 in. in Nebo No. 6 Bore (Analysis No. 1, Table 2). Ordinary light. x 25.

FIG. 2.—Coarse picrite, from 291 ft. 2 in. (6 in. below No. 1), in Nebo No. 6 Bore (Analysis No. 6, Table 2). Ordinary light. x 25.

FIG. 3.—Picrite from 364 ft. in Nebo No. 6 Bore (Analysis No. 8, Table 2). Ordinary light. x 25.

FIG. 4.—Lower crinanite, from 392 ft. in Nebo No. 6 Bore (Analysis No. 3, Table 2). Ordinary light. x 25.